New Physics and the LHC Inverse Problem

Lian-Tao Wang
Harvard University

• Outline

1. Introduction: What is the LHC inverse problem

2. What to expect at the LHC

   Supersymmetry, compositeness

3. How well can we untangle the structure of new physics

   Example: MSSM

4. Conclusion and future directions

LHC: $p\ p$ collider. 2007.

Energy: $E_{\text{cm}} = 14$ TeV

New physics 100 GeV - several TeV $\sim 4\pi \times \Lambda_{\text{EW}}$!

If there is new physics responsible for the stability of the weak scale, it has to come in at $4\pi \times \Lambda_{\text{EW}}$

At the LHC: Fully explore such new physics and start to understand the mystery of the weak scale.

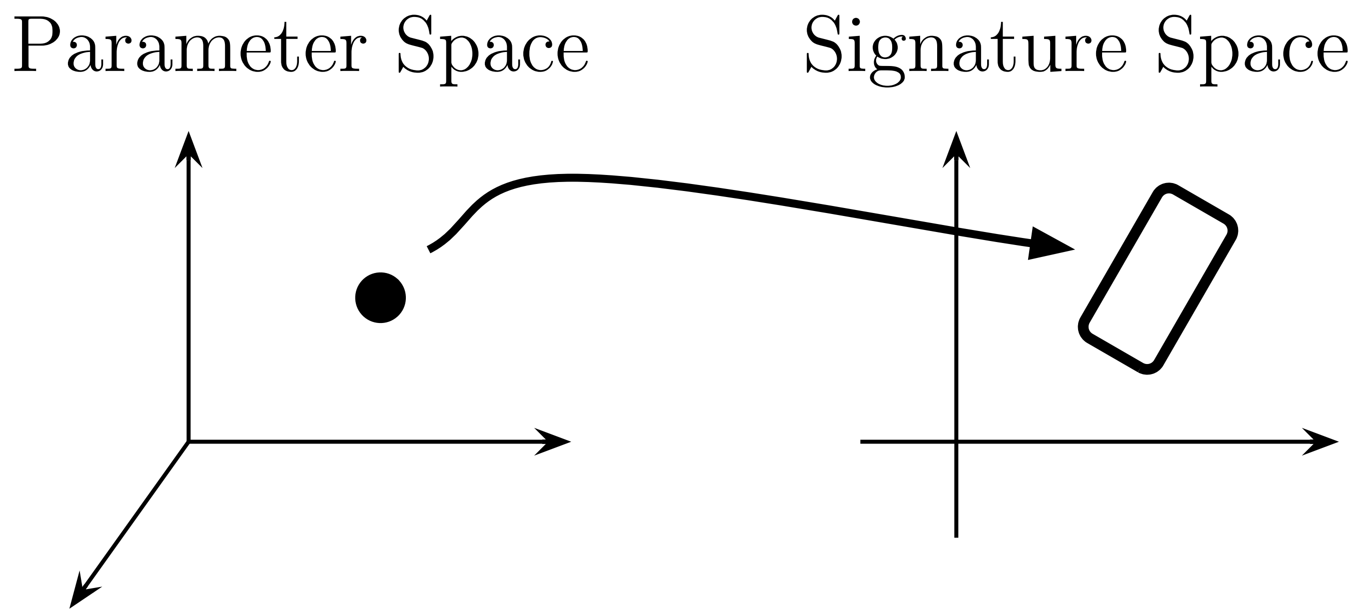
- Connection between theory and experiment

Parameter space $\equiv$ space of all model parameters

$$\Updownarrow$$

Signature space $\equiv$ space of all possible observables

Much work have been focused on: Forward Direction



$\mathcal{L}_{\text{New Physics}} \rightarrow$ LHC signal

Many benchmark studies have been carried out. *

Standard tools developed

Valuable experience has been accumulated

*For example, detailed study SPS points in supersymmetry

The *inverse* problem: LHC data $\rightarrow \mathcal{L}_{\text{New Physics}}$

General Character of the inverse map (One-to-One?)

How can we extract as much information as possible about the underlying theory from data?

• What to expect

In order to study the inverse problem, it is important to understand what to expect first.

Focus of decades of model building and anticipation

new physics $\leftrightarrow$ the mystery of the weak scale

$\longrightarrow$ new (BSM) information about the fundamental theory

• Mystery of the weak scale

1. (big) Hierarchy problem: $\Lambda_{\mathsf{EW}} << M_{\mathsf{Pl}}$

a. How to generate a scale very different from the Planck scale

Logarithmic running $\rightarrow$ exponential separation of scales.

Example: QCD

b. How to stabilize such a scale

Two classes of ideas: supersymmetry, compositeness

• Mystery of the weak scale

2. (little) Hierarchy problem:

Tension between the size of higher dimensional operators and the size of radiative corrections to the electroweak scale.

$$\text{Naturalness of the weak scale} \;:\; \Lambda^2_{\text{NP}} \sim 16\pi^2 \Lambda^2_{\text{EW}}$$

$$\frac{\mathcal{O}^{(5)}}{\Lambda_{\text{NP}}},\ \frac{\mathcal{O}^{(6)}}{\Lambda^2_{\text{NP}}} \to \text{EWPT, flavor, EDM...} \;:\; \Lambda^2_{\text{NP}} \sim (16\pi^2)^2 \Lambda^2_{\text{EW}}$$

Little Hierarchy problem ($\mathcal{O}(1\%)$ tuning) is the primary focus of many model building in the past decade. Many variations of models exist.

• Supersymmetry

The big Hierarchy

Scale generation: hidden sector dynamics

Stability: non-renormalization theorem + soft breaking

Little Hierarchy Problem of supersymmetry breaking

after LEP, B-factories, EDM...

1. FCNC: Generically, there is no "super-GIM" mechanism.

2. CP: Generically, $>>$ Jarlskog, enter at lower loop order

3. m_{Z} vs m_{SUSY}

$$\begin{aligned} \mathrm{EWSB} \rightarrow m_{\mathrm{Z}}^2 &\sim -\mu^2 + m_{H_u}^2 + \ldots \rightarrow m_{\mathrm{Z}}^2 \sim \mu^2 \sim m_{H_u}^2 \\ \mathrm{RGE} \rightarrow m_{H_u}^2 &\sim M_{\mathrm{color}}^2(\tilde{q}, \tilde{g}) \\ M_{\mathrm{color}} &> M_{\mathrm{electroweak}}(\tilde{\ell}, \tilde{W}, \tilde{B}) \end{aligned}$$

Is there natural mechanism of supersymmetry breaking which is consistent with all these constraints?

- Many SUSY breaking scenarios/models:

  GMSB, AMSB, gaugino-MSB, ...

  Gravity mediation with flavor symmetries.

  Special relations between soft parameters.

    e.g., focus point, AMSB+moduli...

  Various string theory constructions...

Many sophisticated model-building tools have been developed to address the little hierarchy problem. Many variations have been constructed.

No clear winner...

Lesson from two decades of model building and experimental search:

If supersymmetry is responsible for the weak scale, its implementation is probably subtle, and/or complicated, and/or strange.

It is worthwhile to explore radically new ideas in model building.

On the other hand, it is hard to be sure that we are getting closer to the answer by refining our current setups.

Is the little hierarchy problem solved by a specific mechanism or by an 1% accident?

Good news: LHC will teach us a lot about it!

• Learning supersymmetry breaking from the LHC

Starting Point:

Low energy effective Lagrangian with the possibility of incorporating all possible supersymmetry breaking models.

$$\text{MSSM} + \delta V(h)$$

Measurement of parameters will lead us toward specific supersymmetry breaking scenarios.

The supersymmetry LHC inverse problem: how well can we extract information about MSSM Lagrangian from the LHC data

Extensions of MSSM should be also studied.

• Non-SUSY: many models, one general framework

1. Large hierarchy:

TC, Randall-Sundrum (Higgsless);   Stability: compositeness

2. Little Hierarchy:

composite Higgs/(little Higgs $\cong$ A^5-Higgs)
many variations: simple group, product group, holographic Higgs...

Z_2 parity: T-parity$\cong$ UED/KK-parity

Localization of fermions in RS $\cong$ elementary/composite mixing

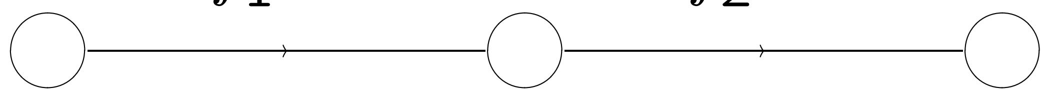
None of them works straightforwardly $\rightarrow$ era of "trick-rich" model building.

We need information from the LHC!

Starting point: Simple parameterization of low energy effective Lagrangian

- Brief outline of a simple setup:*

Global : SP(4) $f_1 e^{\xi_1}$ SP(4) $f_2 e^{\xi_2}$ SP(4)



Gauged : $SU(2)_1$ $SP(4)_c$ $SU(2)_2$

fermions : $t_1^c,\ b_1^c$ q_L, Q t_2^c, b_2^c

Non-linear σ-model with custodial $SU(2)$.

PGB: $h \subset \xi_1 + \xi_2$ ...

Heavy Gauge Boson: $W' \subset \{SU(2)_1\text{-}SU(2)_2, SU(2)_c\}$ ...

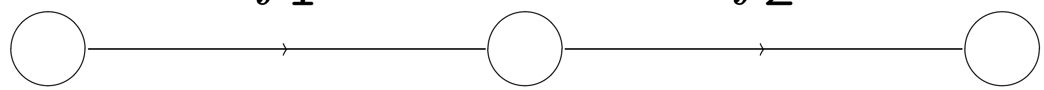
Fermions: SM $+ \{T,\ (t_1^c - t_2^c)\}$ ...

Extensions to different symmetry structures are straightforward if we discover more/less exotics.

*H. Cheng, J. Thaler, LW

• Limits

Global :	$SP(4)$	f_1	$SP(4)$	f_2	$SP(4)$



Gauged :	$SU(2)_1$	$SP(4)_c$	$SU(2)_2$
fermions :	g_1	g_c	g_2

UED/T-Parity:	$g_1 = g_2$
Simple group LH:	$g_1,\ g_2 = 4\pi$
Product group LH:	$g_c = 4\pi$
fermion localization:	$f_2 >> f_1,$ adjusting fermion mass parameters
holographic higgs:	$g_2 = 4\pi$

If compositeness is correct, we will learn the specific realization of it by measuring parameters at the LHC.

- Possible outcomes at LHC:

1. New physics is responsible for the weak scale:

   Big discovery, complicated physics

   rest of the talk: challenges, crucial steps in understanding new physics

2. Very special new physics (hard to miss): $Z' \to \ell^+\ell^-$...

3. Very hard: $\delta\lambda_h$, $\mathcal{O}^{(n>4)}$ (Flavor, EDM, $g_\mu - 2$) ...

• Inverse problems

1. Is it supersymmetry? some preliminary studies*

2. Within a framework:

   identities, scales and interactions of the new particles

   How is little hierarchy problem resolved (dismissed?)

Here, focus on 2.

Information about the structure of the model will help 1. †

*For example, A. Barr hep-ph/0405052

†H. Cheng, I. Low, LW hep-ph/0510225; P. Meade, M. Reece hep-ph/0601124

• Study the LHC inverse problem: MSSM

Low energy supersymmetry is the most compelling candidate for physics beyond the Standard Model

perturbative gauge coupling unification

$\longrightarrow$ deep connection to fundamental theory at high scale

It has rich structures which is typical for a model of new physics responsible for the weak scale

spectacular signals, challenging to interpret

• MSSM parameter space at the LHC: $D_{\text{para}} \sim 20$

Largest cross section, important links in decay chains...

$$M_{\tilde{g}} \quad M_2 \quad M_1 \quad \mu$$

$$m_{\tilde{q}_L}^{1,2} \quad m_{\tilde{q}_R}^{1,2} \quad m_{\tilde{t}_{1,2}} \quad m_{\tilde{b}_{1,2}} \quad A_t \quad A_b$$

$$m_{\tilde{\ell}_L}^{1,2} \quad m_{\tilde{\ell}_R}^{1,2} \quad m_{\tilde{\tau}_{1,2}}$$

$$\tan\beta$$

$$m_h \quad m_A \quad m_H$$

• LHC^{-1} MSSM: What do we want to know?

1. Gauginos: one of the most direct links to fundamental theory

$$M_1,\ M_2,\ M_3 \leftarrow \int d\theta^2 f_a(\{S, T_i ...\}) W^\alpha W_\alpha$$

dilaton domination

$f_a = S,\ F_S$ dominate $\qquad M_1 : M_2 : M_3 \sim 1 : 2 : 6$

anomaly mediation

$f_a \propto \beta_a \log(\sqrt{\Phi\Phi^\dagger})\ F_\Phi \neq 0,\ F_S ... = 0 \qquad M_1 : M_2 : M_3 \sim 3.3 : 1 : 8.8$

many others...

Gauge coupling unification $\leftrightarrow$ gaugino mass unification?

Generic gaugino mass patterns $\leftrightarrow$ subtle supersymmetry breaking

2. 3rd generation particles:

How special are they? Unified (b vs τ...)?

3. Is there an approximate GUT? $SU(2)_R$?

$m_{\tilde{\ell}}$ vs $m_{\tilde{q}}$, m_{left} vs m_{right}

4. μ, the mysterious vector mass for $H_u H_d$

related to supersymmetry breaking?

We will ask these questions when studying the inverse problem.

- Signature space: what do we observe at the LHC?

jet, b-flavored jet, $e^\pm$, $\mu^\pm$, $\tau^\pm$, γ, $\not{E}_T$,

$$\begin{aligned} \rightarrow\ & \mathcal{O}(10)\text{objects per event} \\ & P^i_\mu, \\ & \text{flavor, charge} \end{aligned}$$

Typical SUSY signal:

$$\begin{aligned} pp &\rightarrow \text{[colored superpatners]} + \text{jets} \\ &\rightarrow \text{more jets} + \text{(leptons/photon)} + \not{E}_T \end{aligned}$$

• MSSM signature space at the LHC

1. Number counting: (145 used in our study)

$n_j \times$ jet	b-jet non-b-jet
$+$	
$n_\ell \times$ lepton	ℓ all flavor and charge combo: e.g. $2\ell \rightarrow$21 comb.
$+$	
$n_\gamma \times \gamma$	

More inclusive: Nev, $\mathrm{N}_{1\ell}$, ...

For example: lepton countings contain information such as

color/electroweak, additional source of lepton besides W/Z

2. Kinematical distributions

$\sum P_T$: sum over any combination of interests

$\not{E}_T,\ P_T$	leading lepton, jet, b-jet...
M_{eff}	many combinations:
	3 hardest jets, 2 hardest b-jets....

m_{inv}: many combinations of objects

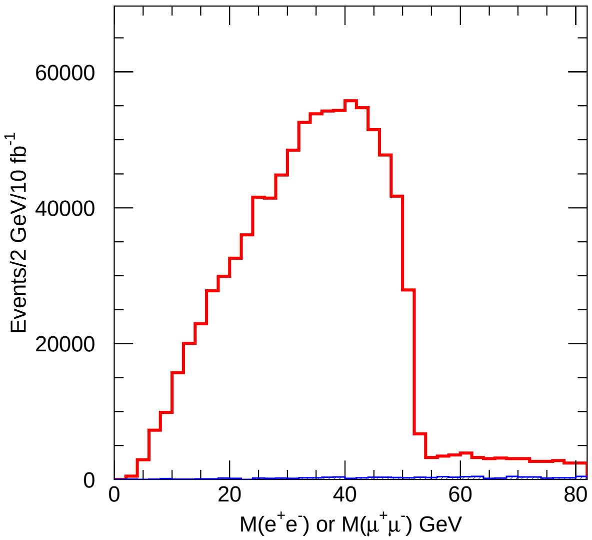
$m_{\text{inv}}(i,j,...),\ i,\ j=\ell,\ b,$ jet

e.g. $m_{\ell+,\ell-}$, m_{bb}, $m_{q\ell\ell}$, $m_{q\ell}$, $m_{qq\ell\ell}\cdots$

Most of Distributions charge/flavor specific, $\mathcal{O}(10)$ bins each

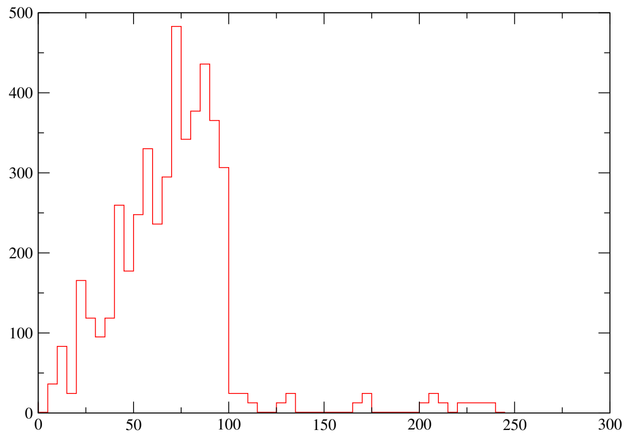
Total: $\mathcal{O}(10^3)$ observables, 1808 used in our study

• Example: end-point and edge



$$\tilde{W} \to \tilde{B} + [Z^*] \to \tilde{B} + \ell^+\ell^-$$

end-point$= M_{\tilde{W}} - M_{\tilde{B}}$



$$\tilde{W} \to [\tilde{\ell}^-] + \ell^+ \to \tilde{B} + \ell^+\ell^-$$

edge$= \sqrt{(M^2_{\tilde{W}} - m^2_{\tilde{\ell}})(m^2_{\tilde{\ell}} - M^2_{\tilde{B}})}/m_{\tilde{\ell}}$

• Difficulties of studying the general inverse problem

We are asking for the property of such an inverse map between generic MSSM parameter space and signature space.

Brute force approach:

Obtaining the full map by densely scanning the MSSM parameter space and simulate for every point.

Not Possible with $\mathcal{O}(10^{20})$!

Statistical approach: *

Expectation value of the number of degeneracies.

Classification of possible degeneracies.

*N. Arkani-Hamed, G. L. Kane, J. Thaler, LW: hep-ph/0512190

- Statistical Method

1. Simulate a relatively small number, m, of models.

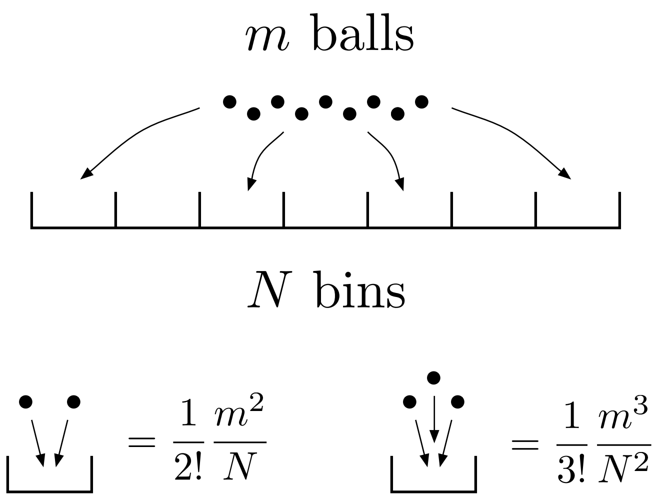
2. Pairwise comparison of the resulting signatures.

   $m(m-1)/2$ pairs

• Power of the Statistical method

Signature bin: a volume element of signature space with finite size determined by experimental error bars.

The signature space spanned by MSSM are divided into $N_{\text{sig.}}$ bins.



$\longrightarrow$

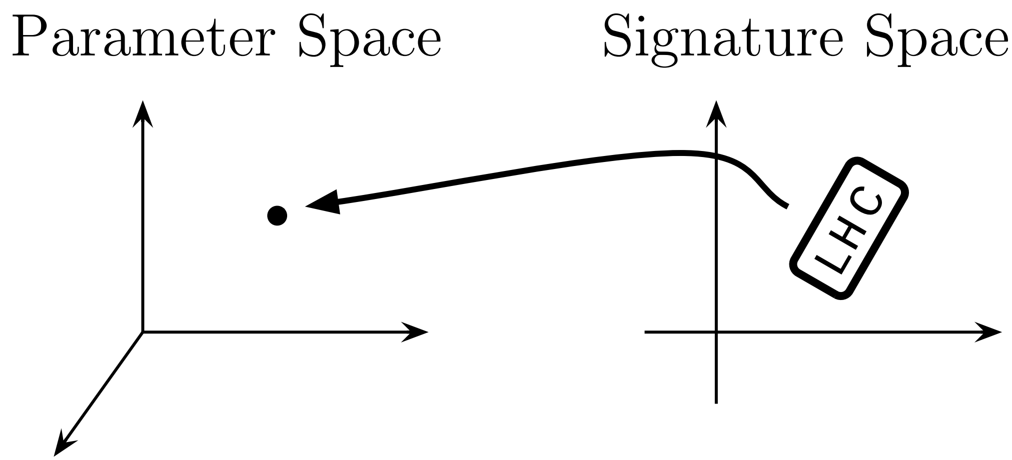
Simulating $m(<< N_{\text{sig.}})$,
chance of getting a degenerate pair:

$< \#\text{doubles} > \sim \frac{m^2}{N_{\text{sig}}}$

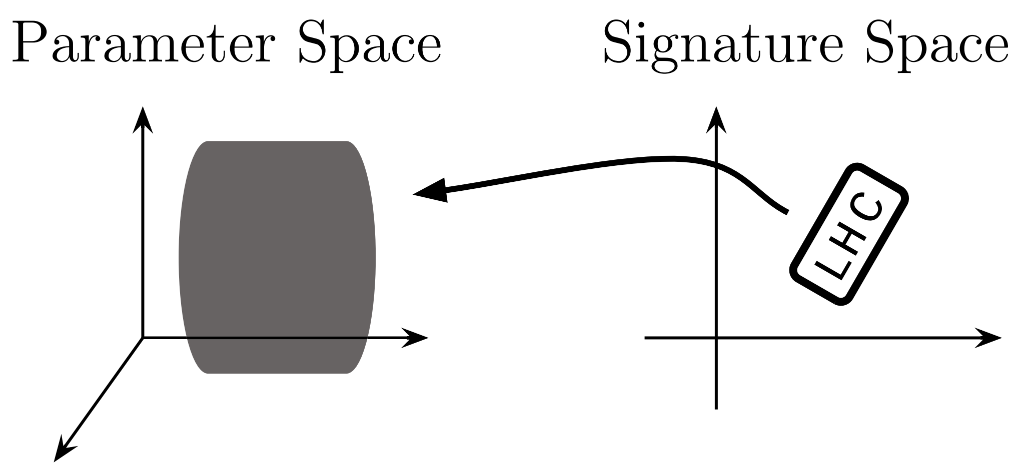
We only need to simulate $m \sim \sqrt{N_{\text{sig}}}$ in order to probe degeneracies!

We obtain an estimate of N_{sig} by counting doubles as a function of m.

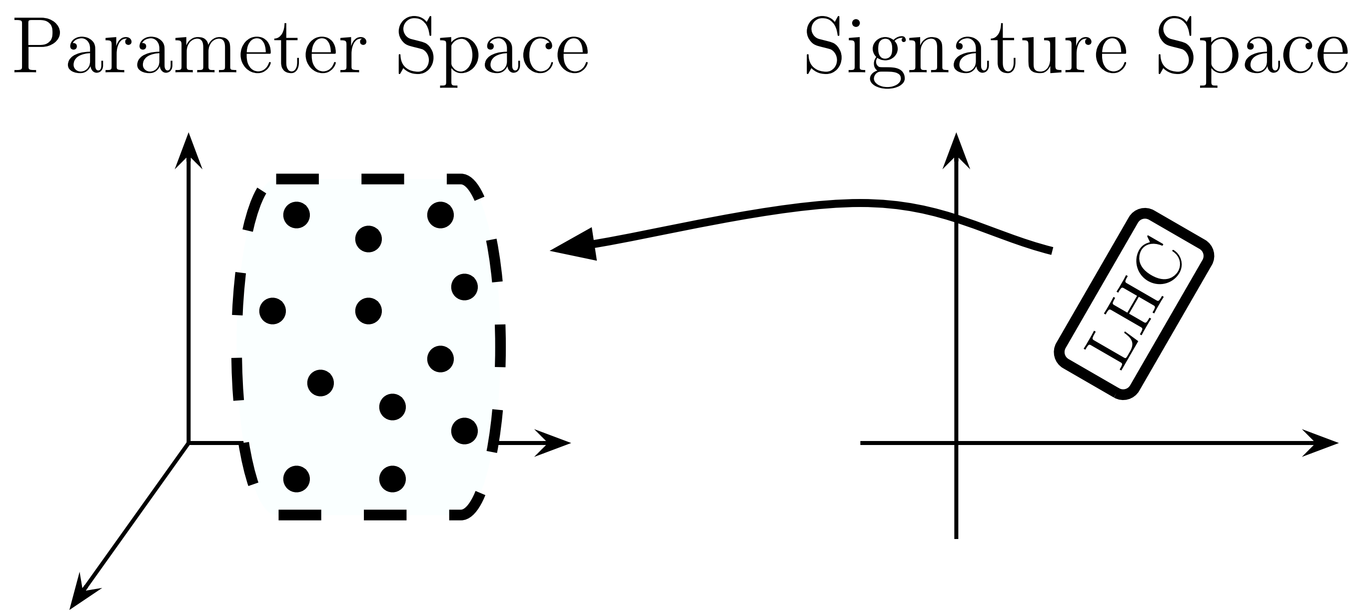
Best of all Possible Worlds



Worst of all Possible Worlds



• The Character of the Inverse Map*



Degeneracies!

Many small footprints in a large overall region.
Interesting structures of degeneracy.

*N. Arkani-Hamed, G. L. Kane, J. Thaler, LW: hep-ph/0512190

• Correlation on the parameter-signature space

Define

$$\Delta P^2 = (\text{Mass Distance})_{IJ} \;=\; \sum_i \frac{|m_i^I - m_i^J|}{\delta m_i}$$

$$\Delta S^2 = (\text{Signature Distance})_{IJ} \;=\; \sum_i \left(\frac{s_i^I - s_i^J}{\delta s_i}\right)^2 \to \chi^2$$

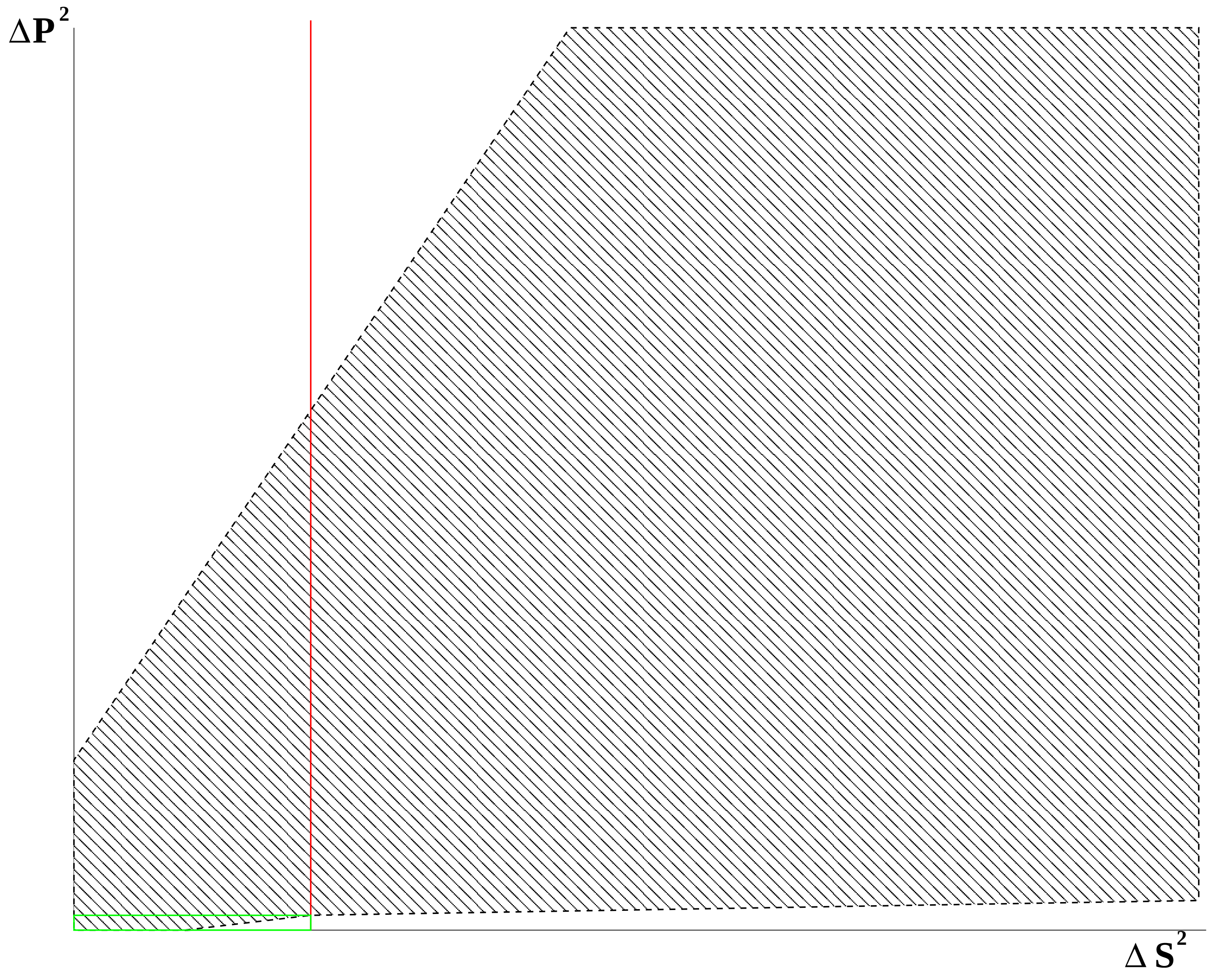
$$\delta s_i \;\leftarrow\; 1/\sqrt{n_i},\ \text{detector eff....: size. Sig. bin}$$

$$\delta m_i \;\leftarrow\; 10\%\ \text{or, GeV}$$

Correlation Function

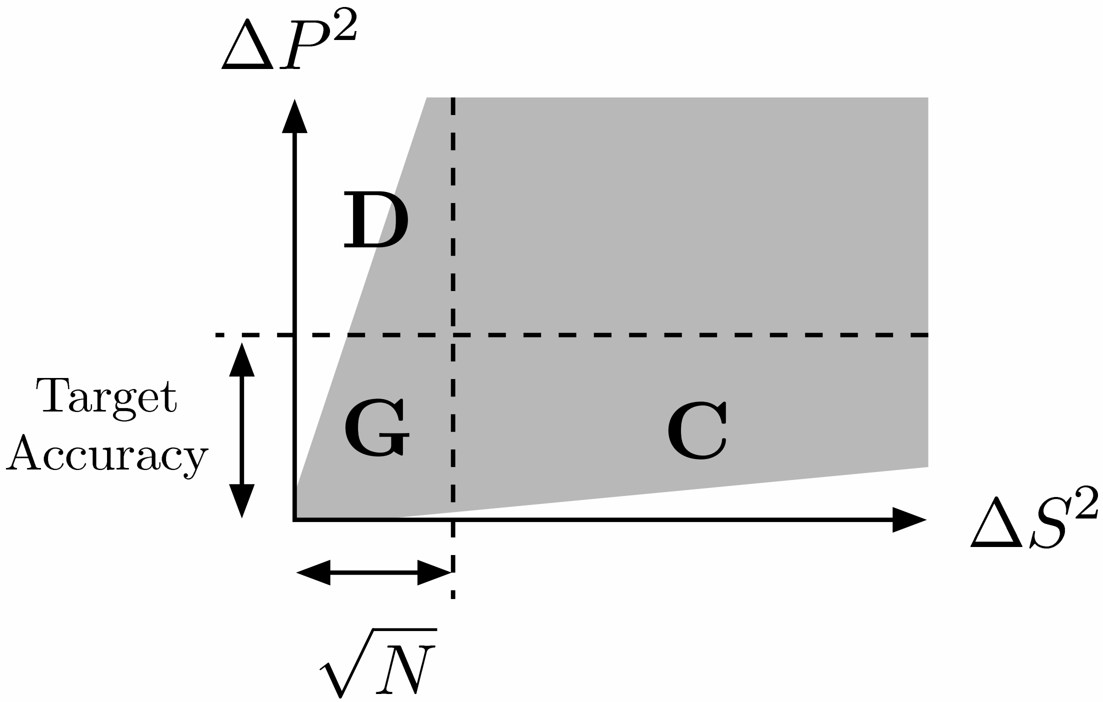
$$\Delta P^2 = \text{Function}(\Delta S^2)$$

MSSM: ΔP^2 vs ΔS^2



(red) signature cut: experimental accuracy, background, fluctuations

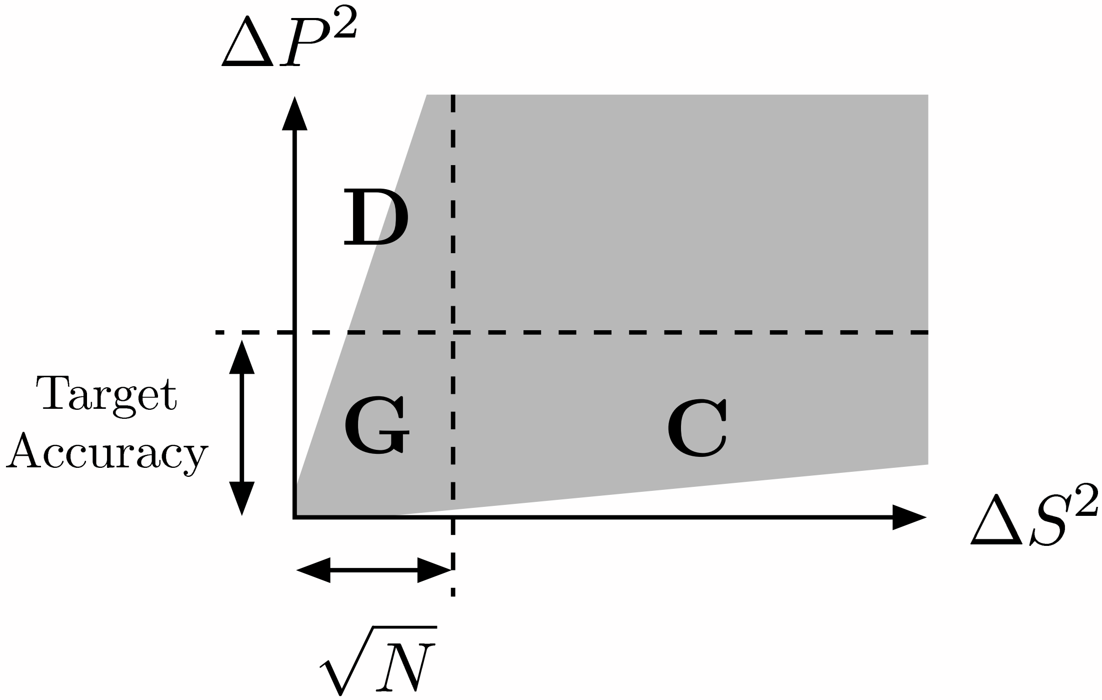
• Counting the degeneracies



$$\langle \text{degeneracies} \rangle = \frac{\mathbf{G}+\mathbf{D}}{\mathbf{G}}$$

$$\langle \text{cliffs} \rangle = \frac{\mathbf{G}+\mathbf{C}}{\mathbf{G}}$$

$$< \text{degeneracies} >= \frac{\text{number of pairs close in signature space}}{\text{number of ``good'' pairs}}$$



$$\langle \text{degeneracies} \rangle = \frac{\mathbf{G} + \mathbf{D}}{\mathbf{G}}$$

$$\langle \text{cliffs} \rangle = \frac{\mathbf{G} + \mathbf{C}}{\mathbf{G}}$$

Cliffs: Sensitivity of the signatures under small variations of parameters. A measure of the size of the image of the inverse map, "islands" (small sub-spaces).

$$< \text{cliffs} >= \frac{\text{number of pairs close in parameter space}}{\text{number of "good" pairs}}$$

• Our result

10 fb^{-1}, pure signal with strong cuts

15% error on total rate, $\sqrt{n}$ error for others

Require 10% accuracy on electroweak-ino, squarks, gluino, etc.

1. <number of degeneracies> $\sim \mathcal{O}(10-100)$

   Not unique! Not impossibly large either.

2. A lot of cliffs $\mathcal{O}(10^3) \longrightarrow$ Islands are small

   Good sensitivity but qualitative different degeneracies.

- Dimension of the Signature space

How does # of signature bins scale with size of the signature bin $|\delta s|$?

$$N_{\text{sig}} \sim |\delta s|^{-D}$$

$$D_{\text{sig}} \sim \text{Dim. of Sig. space}$$

A fit to our data set show that

$$D_{\text{sig}} \sim (7) < \#\ \text{of parameters}$$

$\longrightarrow$ degeneracies!

Degeneracies have structures.

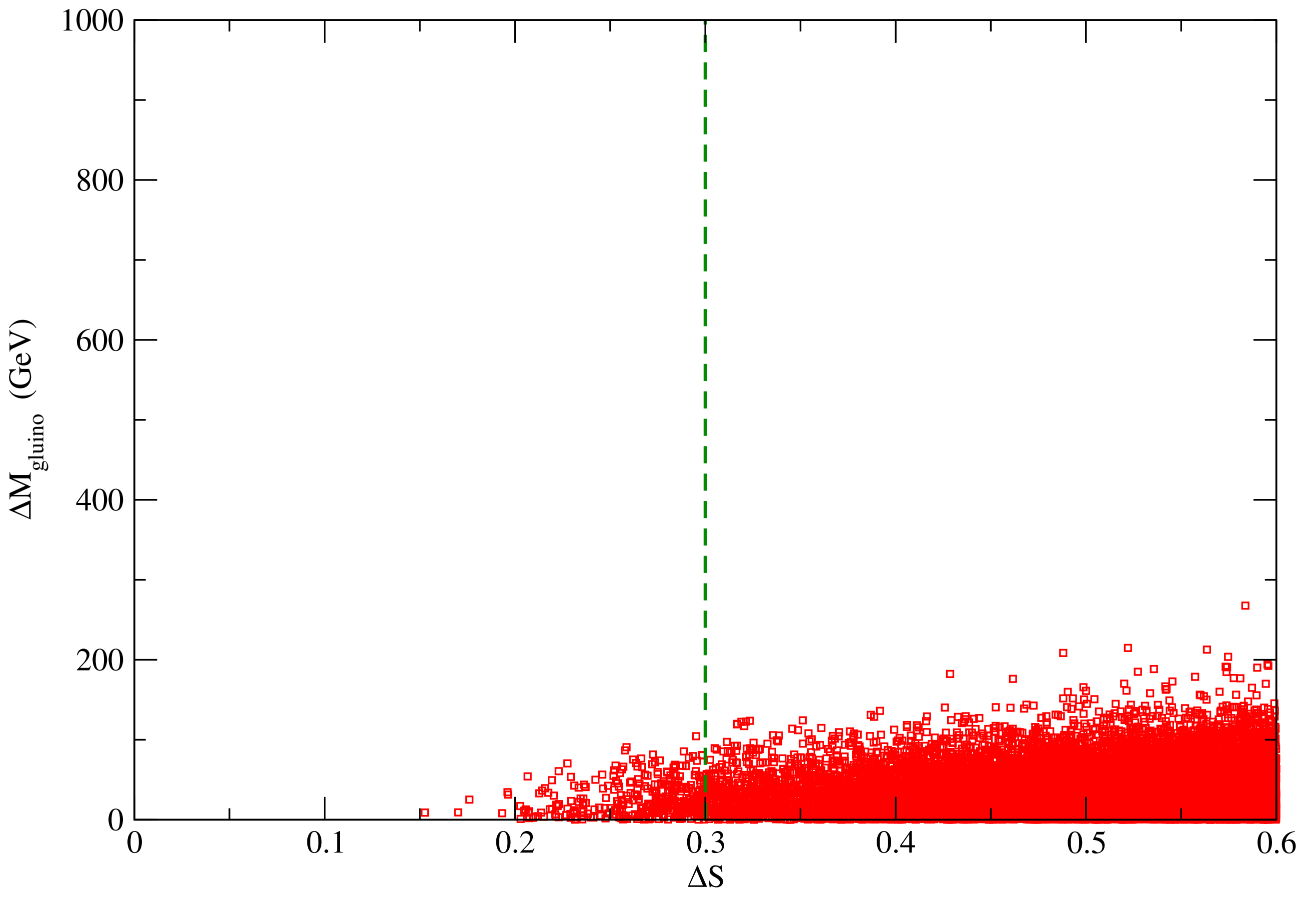
Important information about how to find degeneracies.

Correlation function

$$\Delta M_i = F(\Delta S)$$

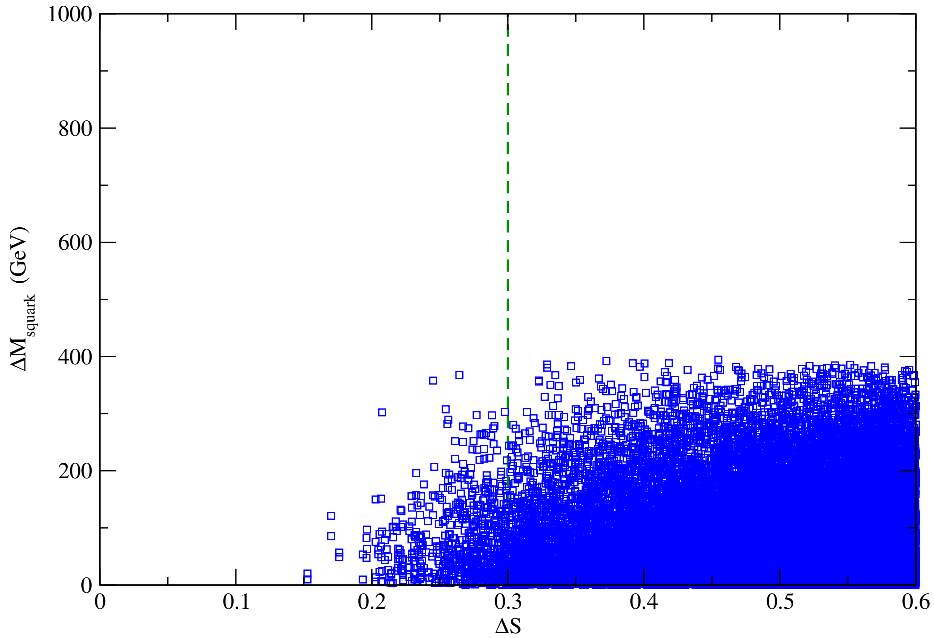
How individual parameter differs among degenerate pairs?

- Gluino



1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
0.6
ΔM_{gluino} (GeV)
ΔS

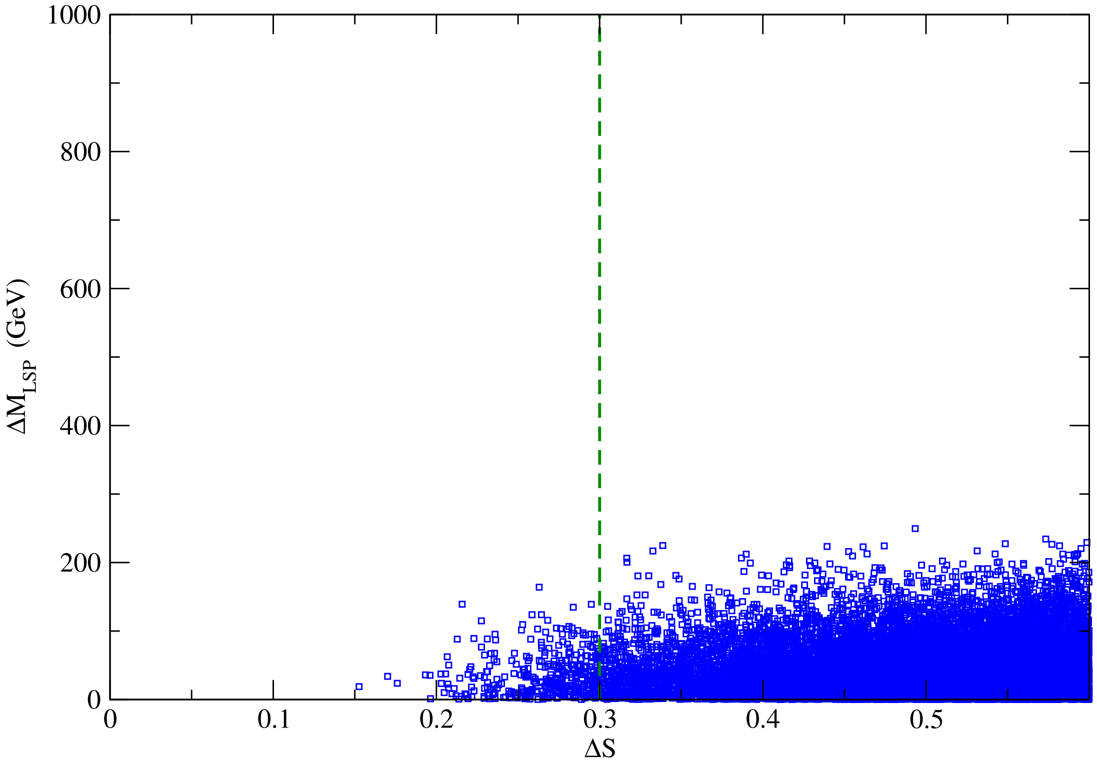
- squark



Good sensitivity on the overall scale. Poor on left-right splitting.

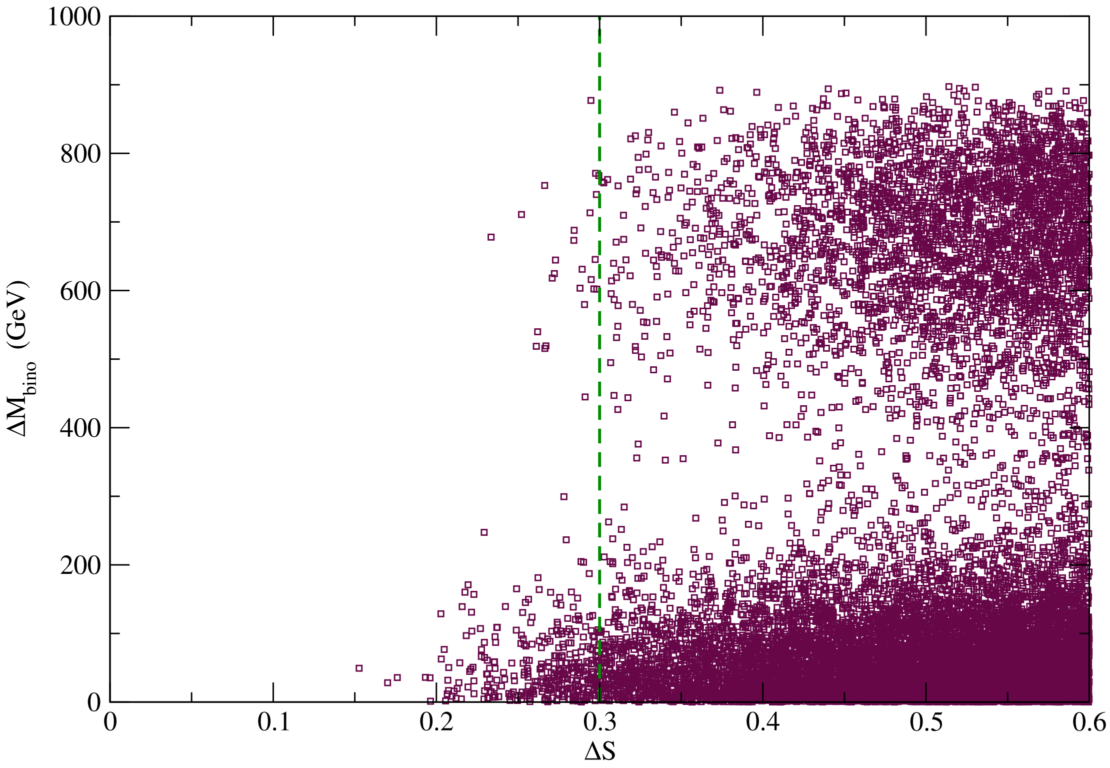
Similar result for slepton.

- Lightest superpartner (LSP)



Reasonable handle on the LSP mass.

• Electroweak-inos: Bino



Similar structures for wino and Higgsino

Large ambiguity in the identity of the LSP

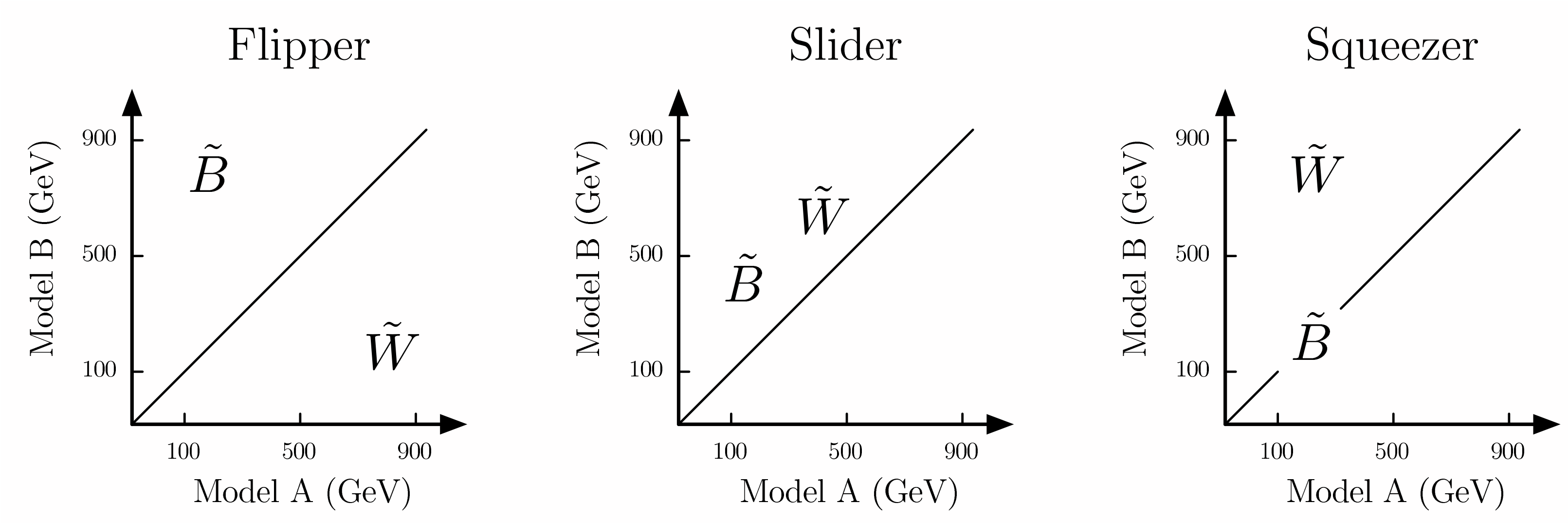
• Classification of degeneracies

Electroweak-ino

flipper: Mass, but not mass eigenstate

slider: only measure mass differences

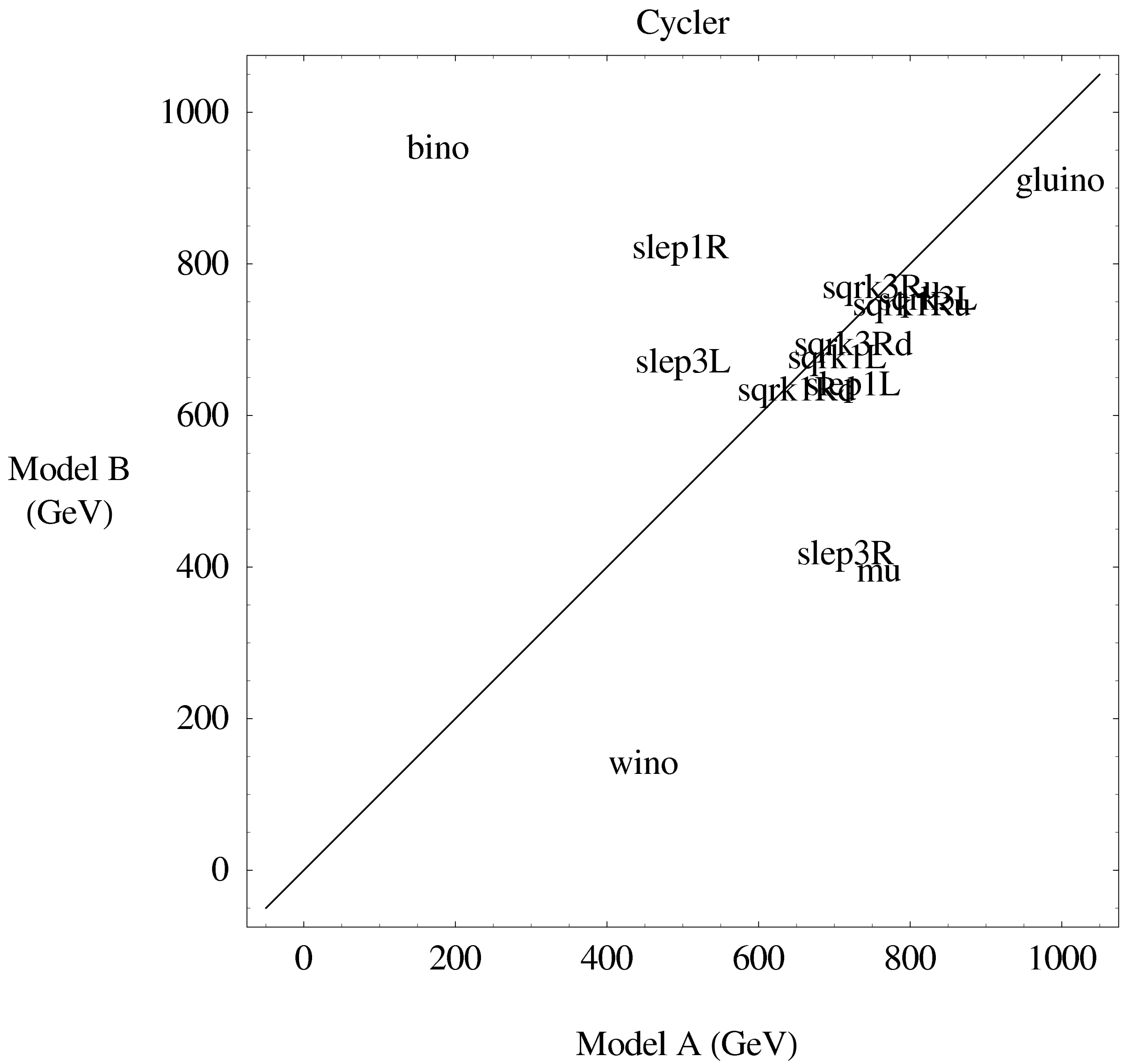
squeezer: can not measure soft stuff



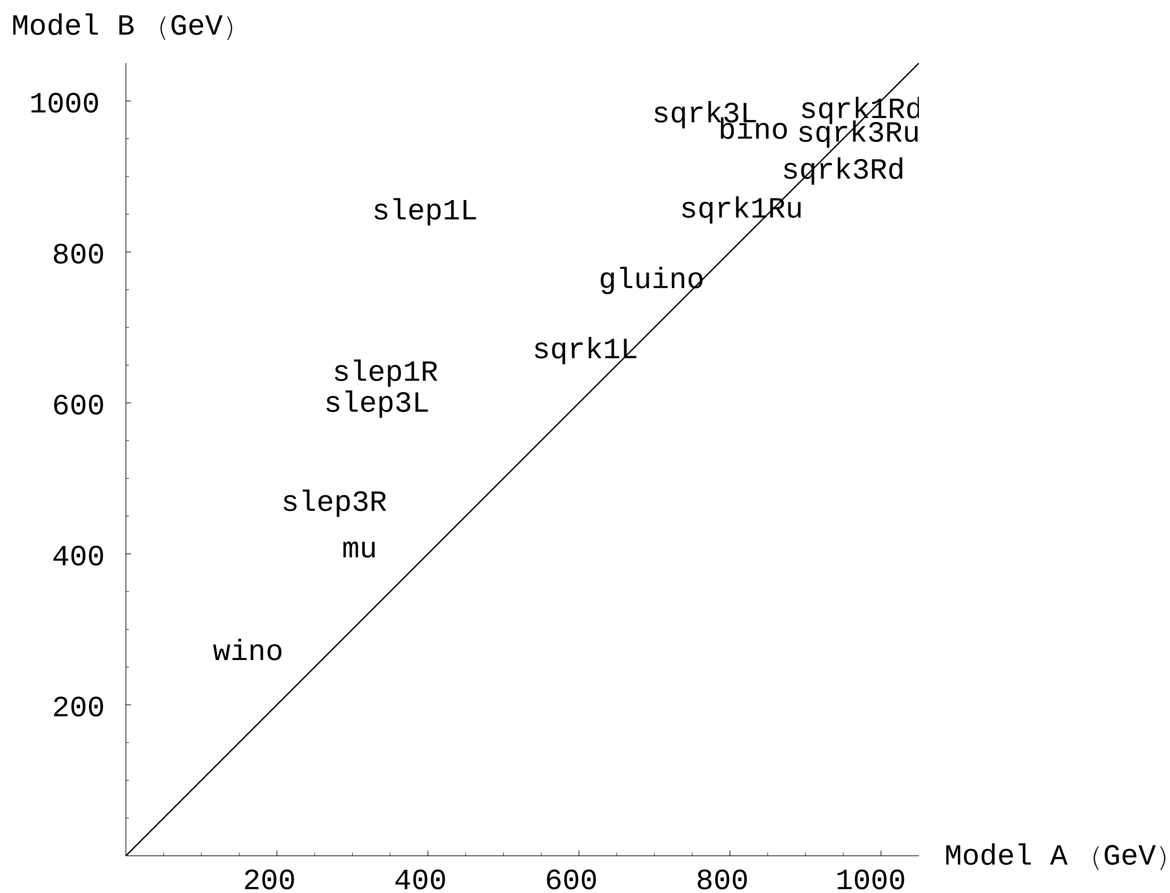
sfermion: LR split...

With light slepton: LR+ino combination flippers

1. flipper:

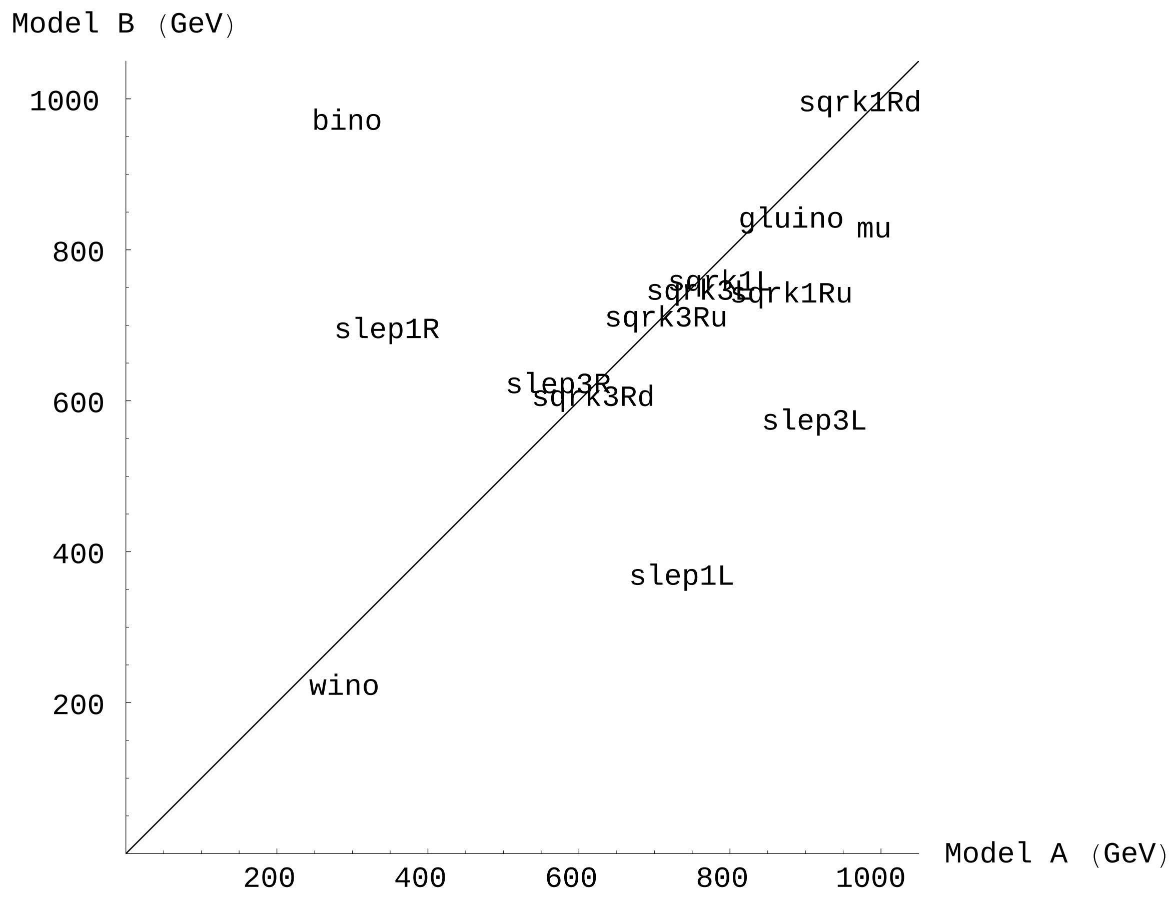

Cycler
bino
gluino
slep1R
sqrk3Ru
sqrk1Ru
slep3L
sqrk3Rd
sqrk1L
slep1L
sqrk1Rd
slep3R
mu
wino
Model B
(GeV)
Model A (GeV)
0
200
400
600
800
1000

Slider:



Model B (GeV)
1000
800
600
400
200
sqrk3L
bino
sqrk1Rd
sqrk3Ru
sqrk3Rd
slep1L
sqrk1Ru
gluino
sqrk1L
slep1R
slep3L
slep3R
mu
wino
200
400
600
800
1000
Model A (GeV)

Squeezers:



Model B (GeV)
1000
800
600
400
200
200
400
600
800
1000
Model A (GeV)
bino
sqrk1Rd
gluino
mu
sqrk1L
sqrk3
sqrk1Ru
sqrk3Ru
slep1R
slep3R
sqrk3Rd
slep3L
slep1L
wino

- Why are there degeneracies?

Colored particle $\to$ jets + ... :

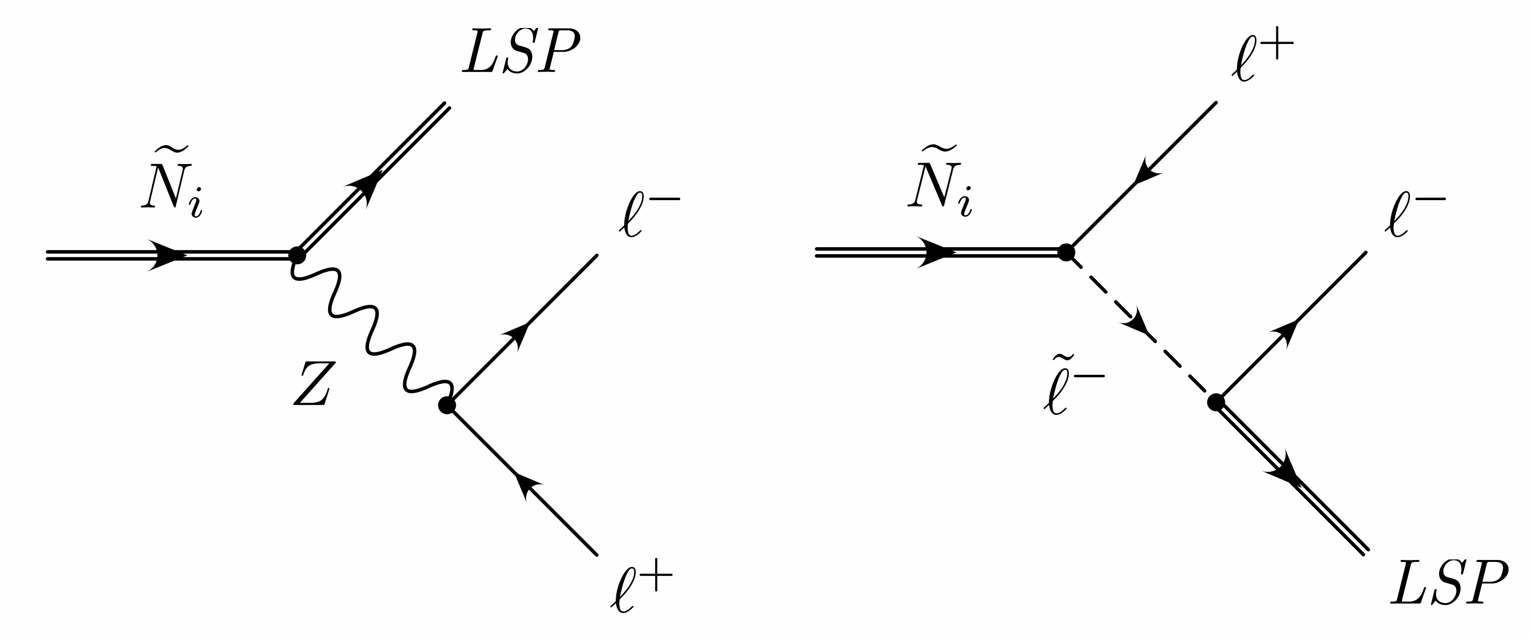
No flavor/charge information from the jets, except b-tag.

Electroweak-ino decay:

most of information in $W/Z \to$ leptons

h difficult: b-tagging, SUSY background

On-shell slepton in the decay chain will help!



on-shell slepton enhances significantly lepton signatures

More charge and flavor information

More handles on ino identities

However, no strong reason to expect this is generically true

Lessons from MSSM study:

For a generic point in MSSM parameter space,

there are qualitatively different points with very similar experimental outcomes at the LHC.

gaugino masses, μ, LR split, ...

To correctly interpret the new physics from the LHC signals, we have to confront these issuses.

Effects of the Standard Model background and luminosity need to be studied more carefully.

Find the degenerate points: the most important first step

Small regions + large distance in between $\rightarrow$ very hard problem

conventional algorithm won't work

A lot of experience and intuition are needed

go beyond our qualitative classification

signature-parameter correlation in many different scenarios

factor in detector performance...

We have to be innovative.

New methods to distinguish the degeneracies.

Difficult. Significant progress can be made.

a. New independent observables

Easy to evaluate effectiveness $\leftarrow D_{\text{sig}}$

b. Specific models $\rightarrow$ Specific correlations between observables.

c. Include complementary effects of other non-LHC observables.

$g_\mu - 2$, B-decays, EDMs.

direct/indirect detection of Dark matter.

Iterative process between theory and experiment

Experiment $\longrightarrow$ hints of underlying theory

Theory $\longrightarrow$ subtle correlations between observables

Future Directions

Effects of the Standard Model background and luminosity need to be studied more carefully.

Our work needs to be extended to

Extensions of MSSM: NMSSM, $U(1)'$+MSSM, $SU(2)_R$ ...

Compositeness scenario

...

LHC at luminosity $10^{33} cm^{-2} s^{-1}$:

$\longrightarrow$ $\tilde{g}$, $\tilde{q}$ $\sim$ 1 TeV : 1,000 events per month

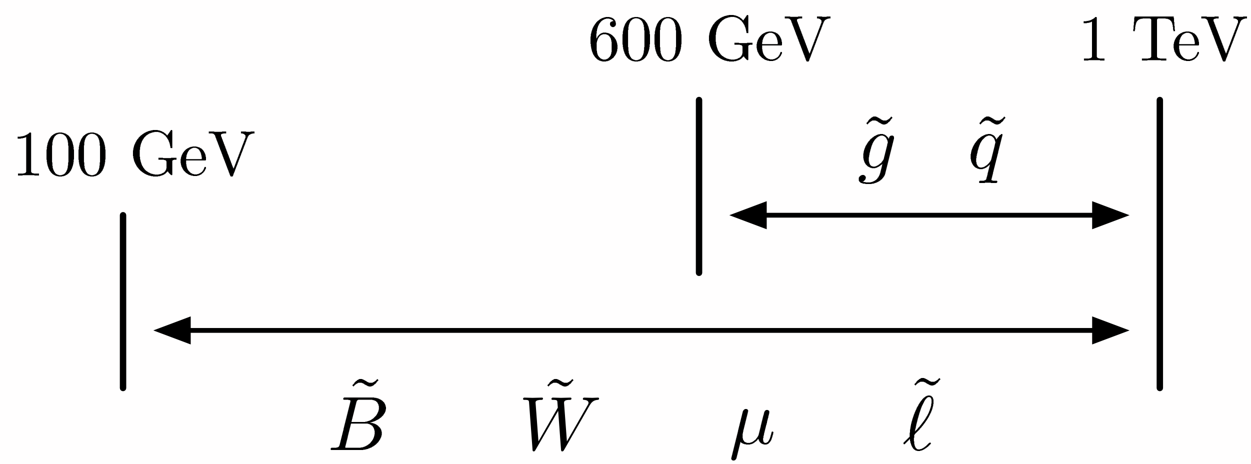
$\longrightarrow$ Discover supersymmetry up to 2 TeV ($\tilde{g}$) in a year

h, $t\bar{t}$, B_{S}...

Lots of work to do!

- backups

- More specifically:



$$\tilde{q}\left\{\begin{array}{lll} \tilde{q}_L & \tilde{q}_{Ru} & \tilde{q}_{Rd} \\ \tilde{q}^3_L & \tilde{q}^3_{Ru} & \tilde{q}^3_{Rd} \end{array}\right. \qquad \tilde{\ell}\left\{\begin{array}{ll} \tilde{\ell}_L & \tilde{\ell}_R \\ \tilde{\ell}^3_L & \tilde{\ell}^3_R \end{array}\right.$$

Constraints: Nothing more than 50 GeV decoupled
Max Colored > Max Electroweak-ino > Max Slepton

N_{MSSM} vs $N_{\text{Sig. Bin}}$

1. N_{MSSM}:

Number of different MSSMs (measured by desired parameter accuracies)

2. $N_{\text{Sig. Bin}}$:

Signature bin: small neighborhood of signature space whose volume is determined by experimental error $|s|$.

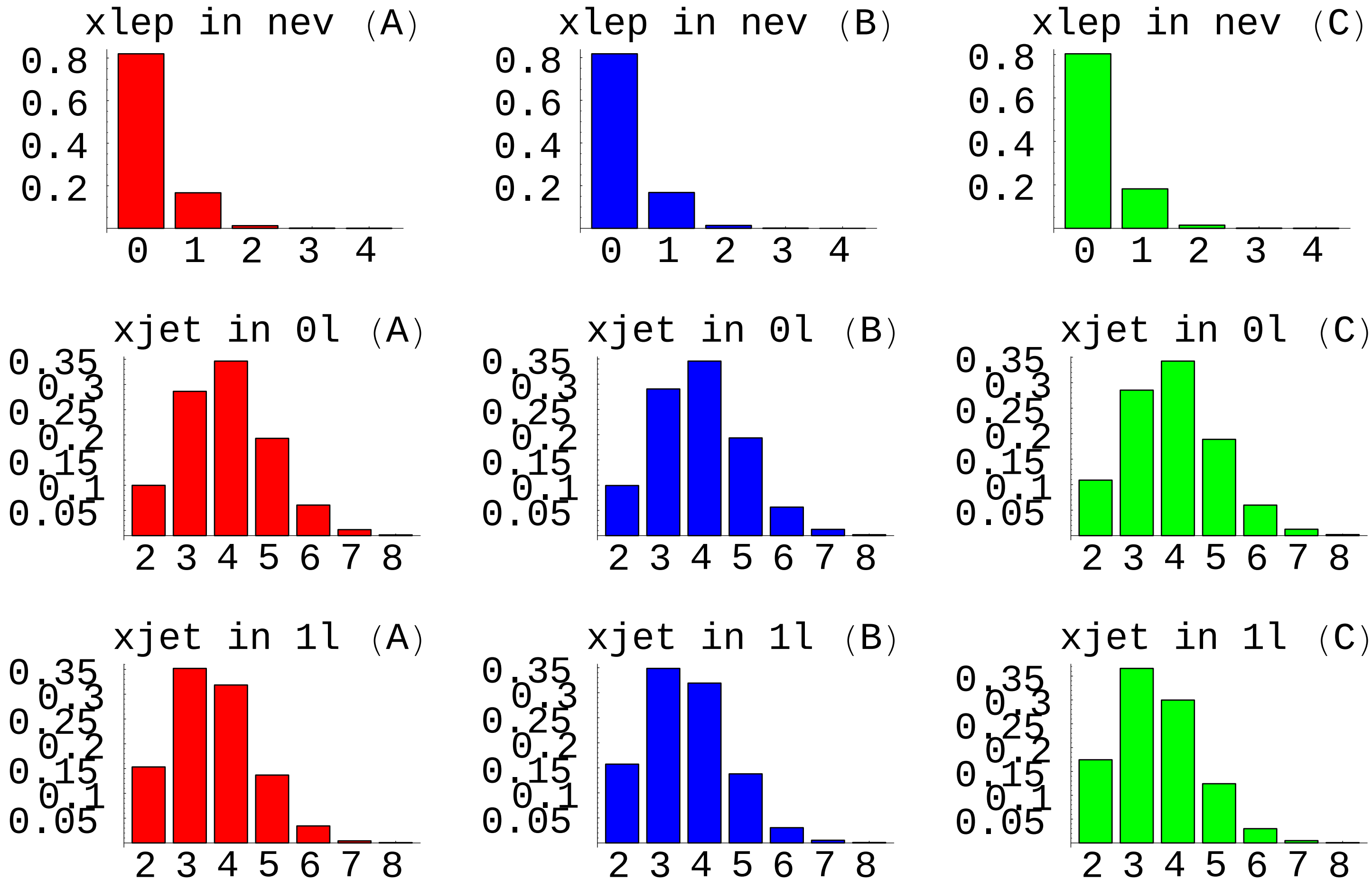
Number of Experimentally distinguishable outcomes

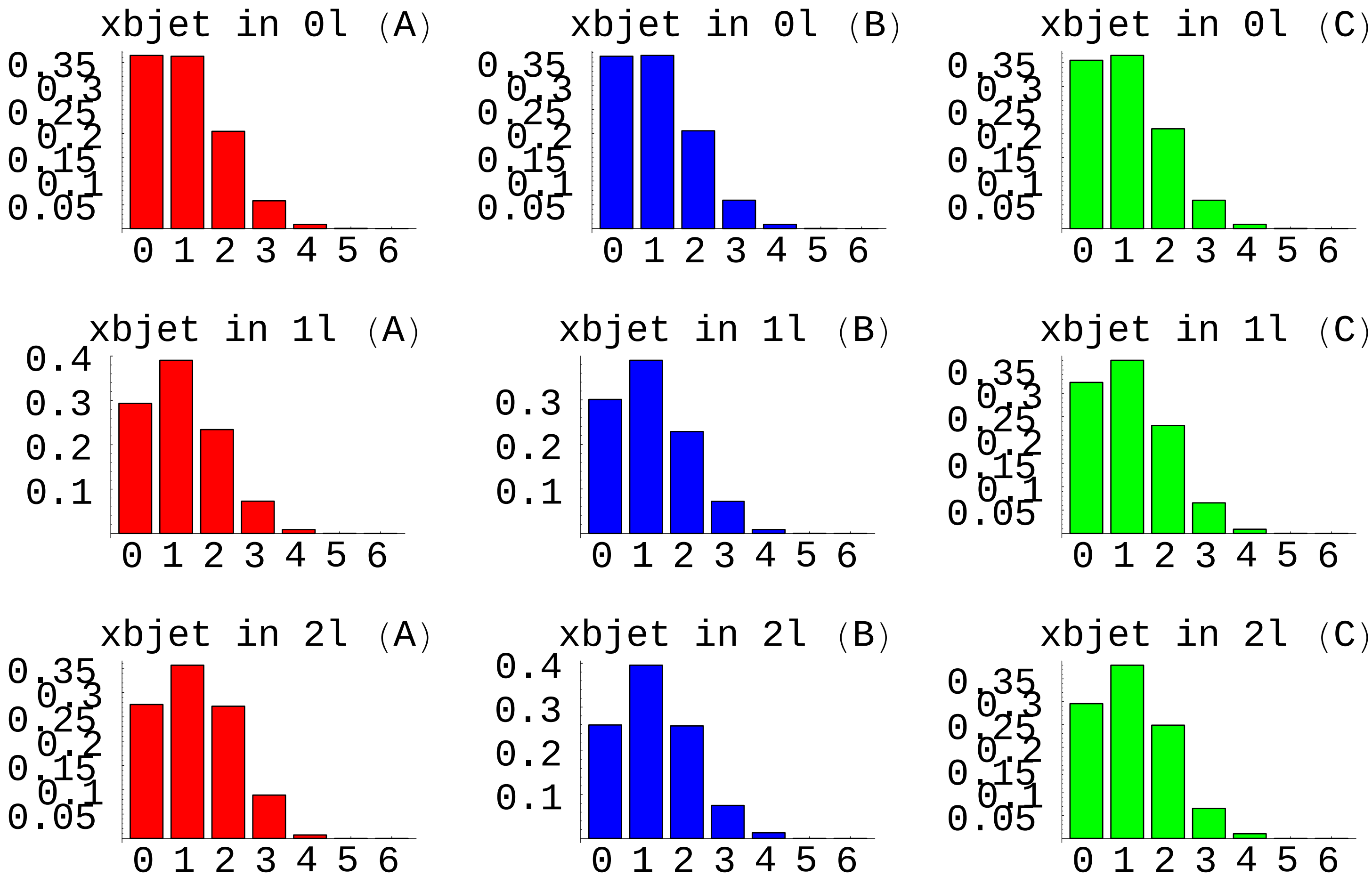
Comparison:

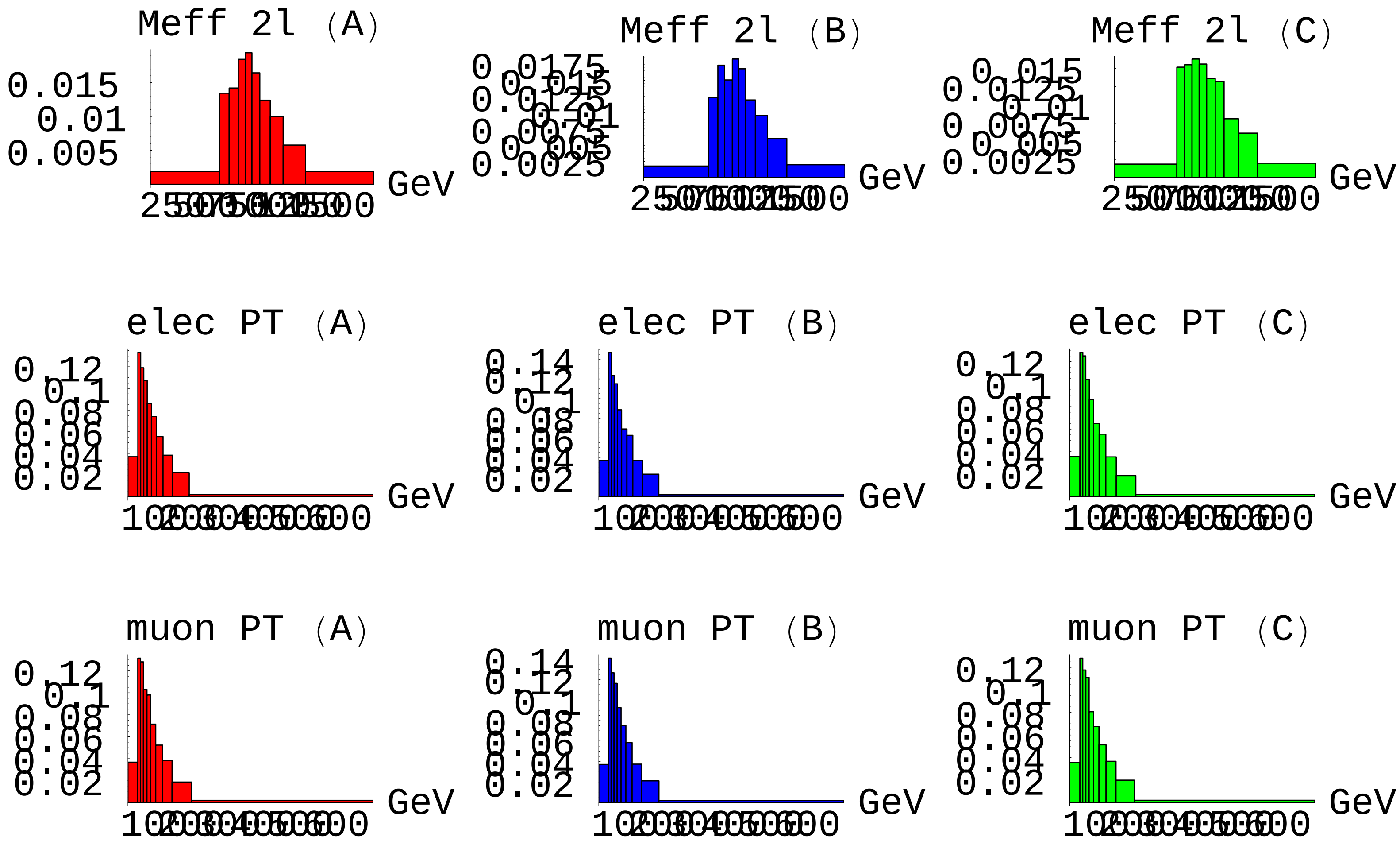
$$N_{\text{MSSM}} >, \ =, \ \text{or} \ < N_{\text{Sig. Bin}}$$

If $N_{\text{MSSM}} > N_{\text{Sig. Bin}} \longrightarrow$ Degeneracies.

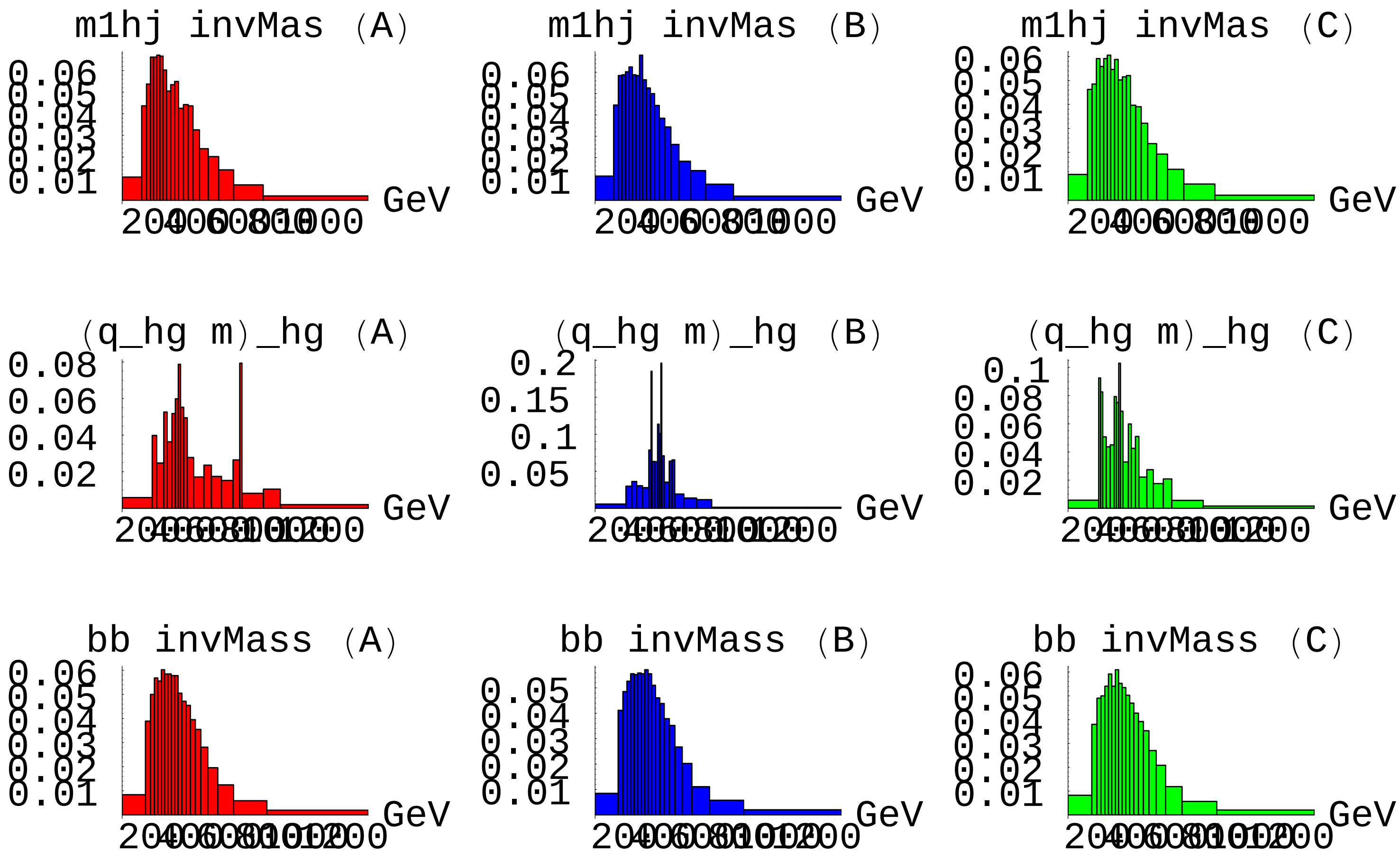
- Comparison: Same vs different Models



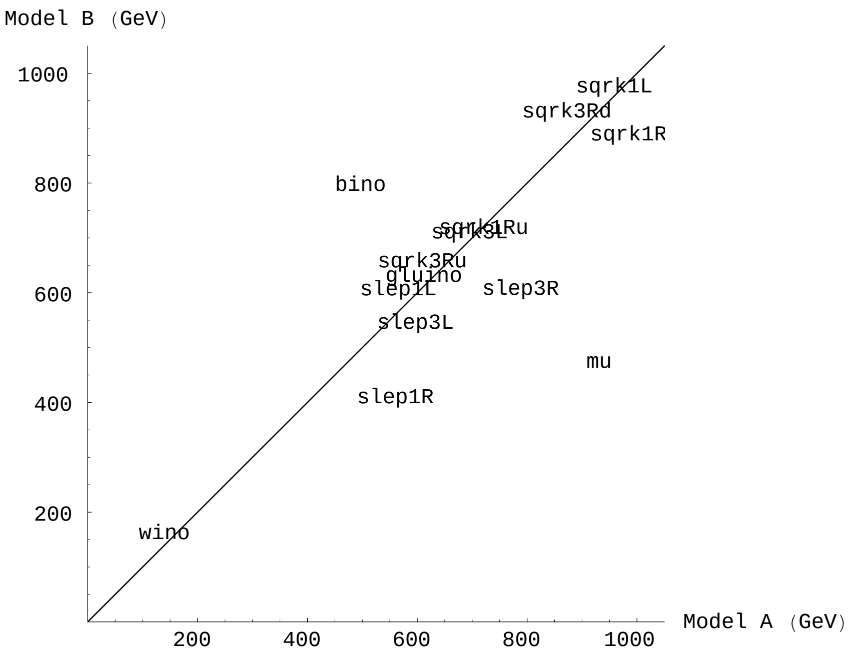

xbjet in 0l (A)
0.35 0.3 0.25 0.2 0.15 0.1 0.05
0 1 2 3 4 5 6
xbjet in 0l (B)
0.35 0.3 0.25 0.2 0.15 0.1 0.05
0 1 2 3 4 5 6
xbjet in 0l (C)
0.35 0.3 0.25 0.2 0.15 0.1 0.05
0 1 2 3 4 5 6
xbjet in 1l (A)
0.4 0.3 0.2 0.1
0 1 2 3 4 5 6
xbjet in 1l (B)
0.3 0.2 0.1
0 1 2 3 4 5 6
xbjet in 1l (C)
0.35 0.3 0.25 0.2 0.15 0.1 0.05
0 1 2 3 4 5 6
xbjet in 2l (A)
0.35 0.3 0.25 0.2 0.15 0.1 0.05
0 1 2 3 4 5 6
xbjet in 2l (B)
0.4 0.3 0.2 0.1
0 1 2 3 4 5 6
xbjet in 2l (C)
0.35 0.3 0.25 0.2 0.15 0.1 0.05
0 1 2 3 4 5 6

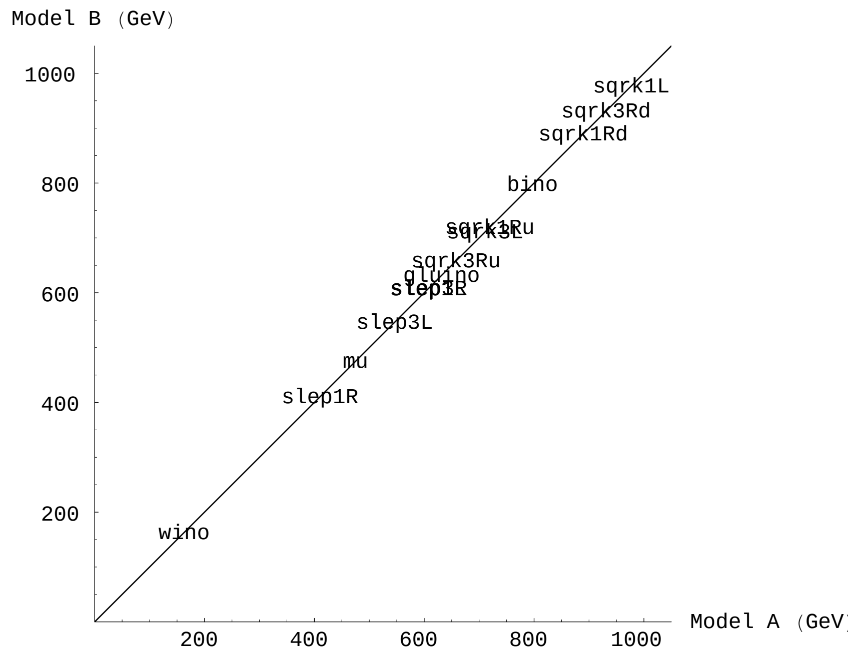

Meff 2l (A)
0.015
0.01
0.005
GeV
Meff 2l (B)
GeV
Meff 2l (C)
GeV
elec PT (A)
GeV
elec PT (B)
GeV
elec PT (C)
GeV
muon PT (A)
GeV
muon PT (B)
GeV
muon PT (C)
GeV

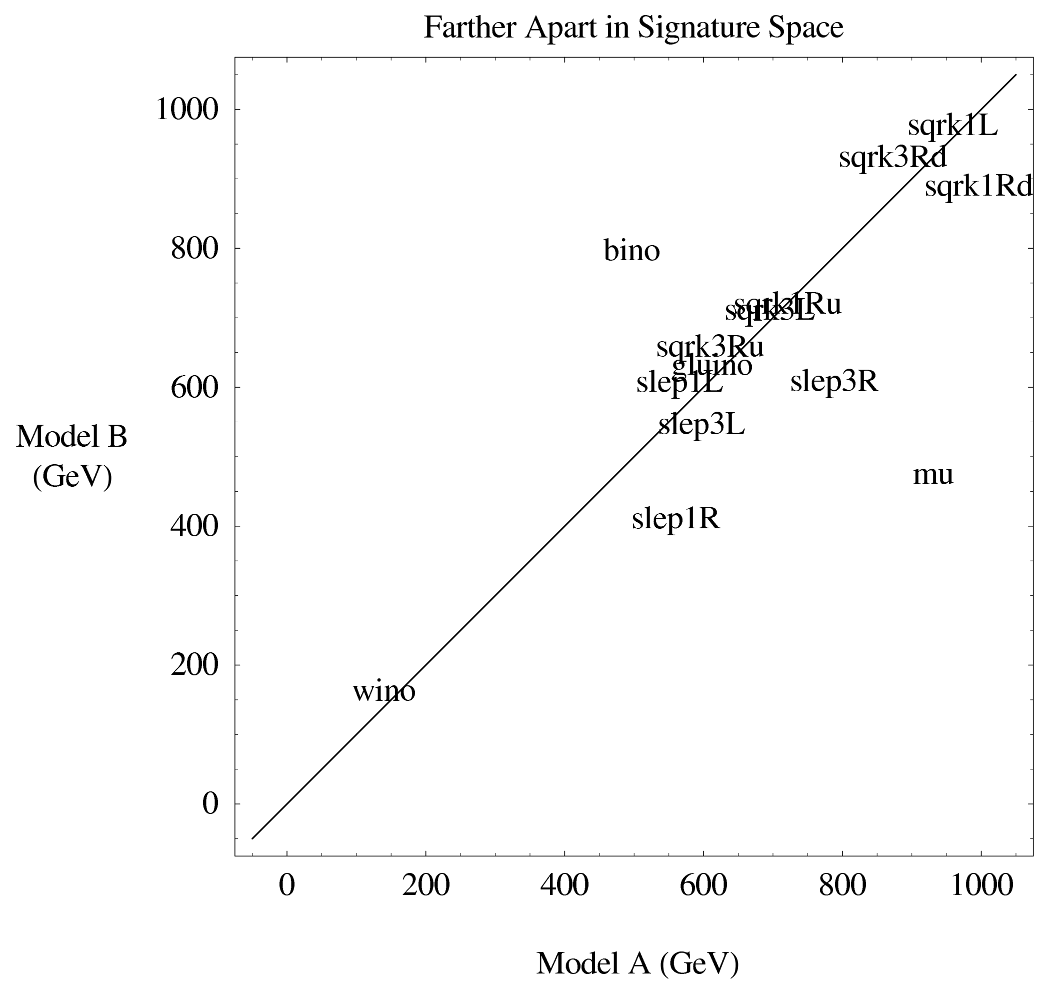
A = B or B = C (or A = C) ?

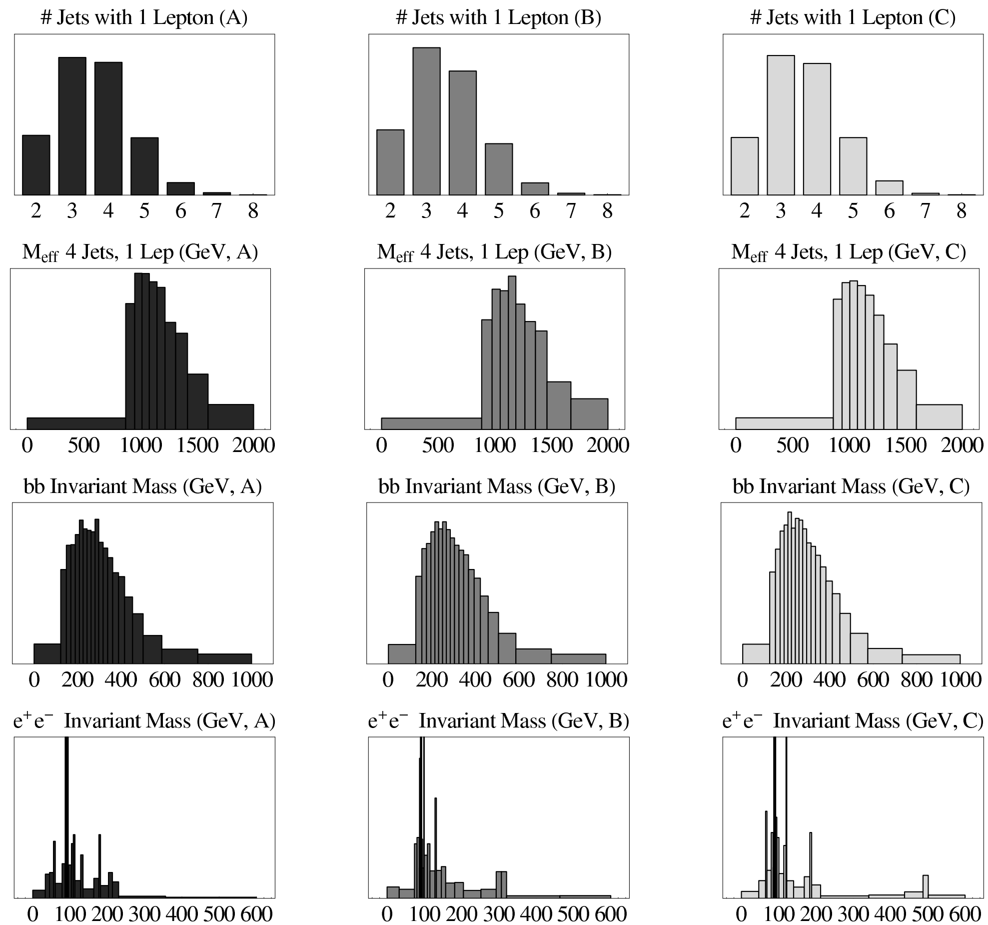

m1hj invMas (A)
m1hj invMas (B)
m1hj invMas (C)
(q_hg m)_hg (A)
(q_hg m)_hg (B)
(q_hg m)_hg (C)
bb invMass (A)
bb invMass (B)
bb invMass (C)
GeV

the answer: A = B

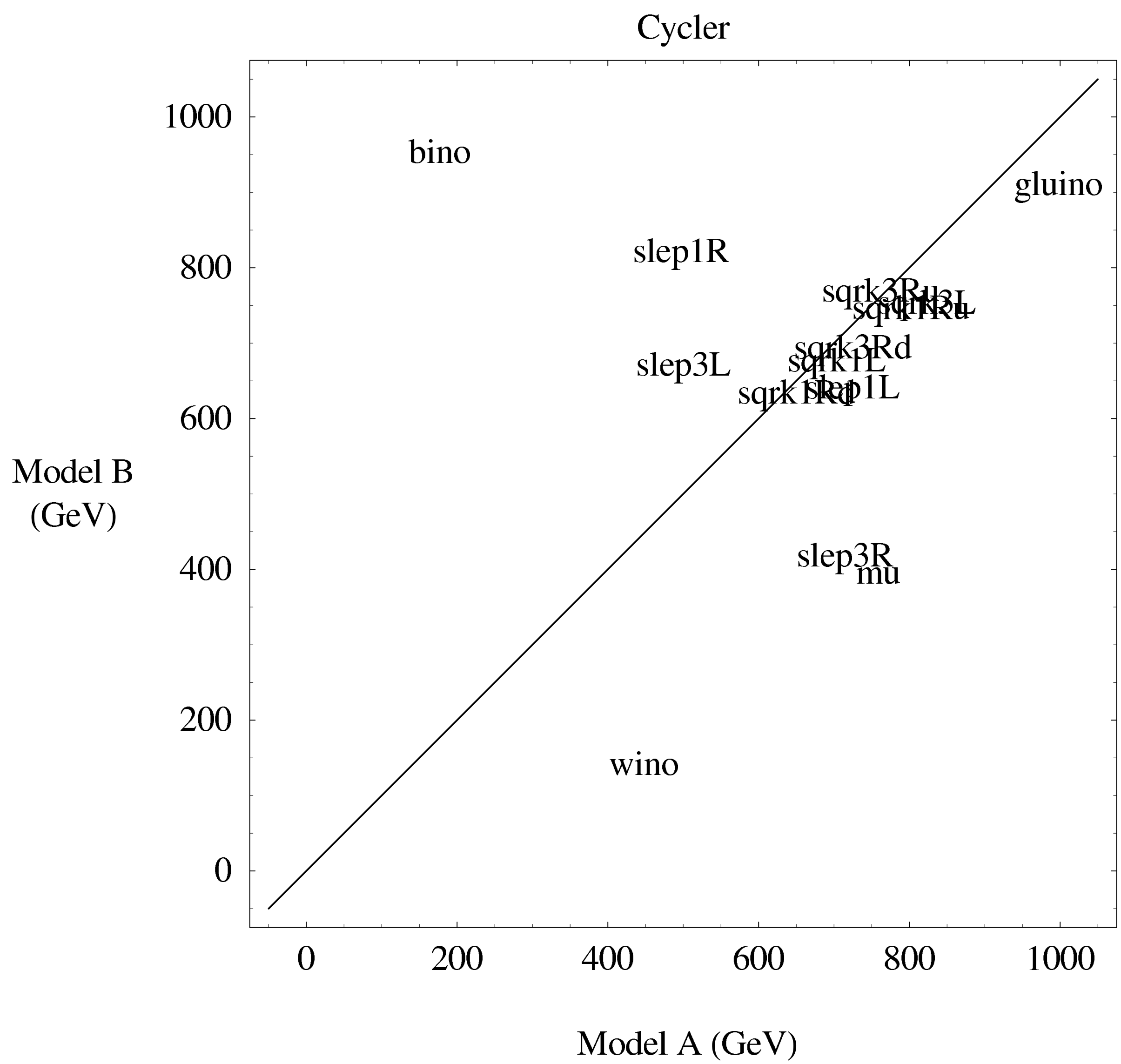




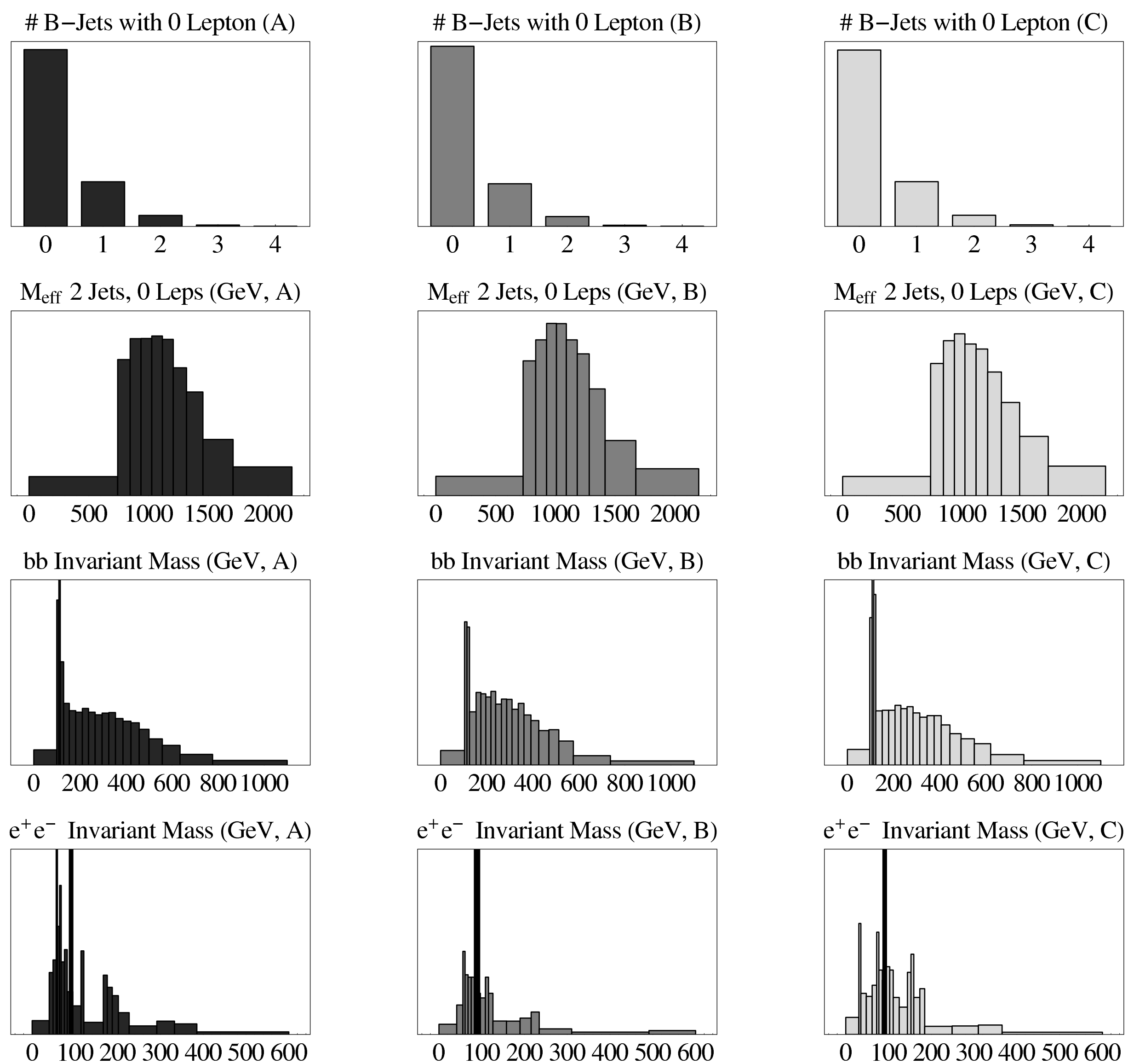

Farther Apart in Signature Space
Model B
(GeV)
Model A (GeV)
0
200
400
600
800
1000
wino
bino
slep1R
slep3L
slep1L
gluino
sqrk3Ru
sqrk3L
sqrk1Ru
slep3R
mu
sqrk1L
sqrk3Rd
sqrk1Rd



Jets with 1 Lepton (A)
2 3 4 5 6 7 8
Jets with 1 Lepton (B)
2 3 4 5 6 7 8
Jets with 1 Lepton (C)
2 3 4 5 6 7 8
M_{eff} 4 Jets, 1 Lep (GeV, A)
0 500 1000 1500 2000
M_{eff} 4 Jets, 1 Lep (GeV, B)
0 500 1000 1500 2000
M_{eff} 4 Jets, 1 Lep (GeV, C)
0 500 1000 1500 2000
bb Invariant Mass (GeV, A)
0 200 400 600 800 1000
bb Invariant Mass (GeV, B)
0 200 400 600 800 1000
bb Invariant Mass (GeV, C)
0 200 400 600 800 1000
e^+e^- Invariant Mass (GeV, A)
0 100 200 300 400 500 600
e^+e^- Invariant Mass (GeV, B)
0 100 200 300 400 500 600
e^+e^- Invariant Mass (GeV, C)
0 100 200 300 400 500 600



Cycler
Model B (GeV)
Model A (GeV)
0
200
400
600
800
1000
bino
slep1R
slep3L
wino
gluino
sqrk3Rd
sqrk1L
slep3R
mu



B−Jets with 0 Lepton (A)
0 1 2 3 4
B−Jets with 0 Lepton (B)
0 1 2 3 4
B−Jets with 0 Lepton (C)
0 1 2 3 4
M_eff 2 Jets, 0 Leps (GeV, A)
0 500 1000 1500 2000
M_eff 2 Jets, 0 Leps (GeV, B)
0 500 1000 1500 2000
M_eff 2 Jets, 0 Leps (GeV, C)
0 500 1000 1500 2000
bb Invariant Mass (GeV, A)
0 200 400 600 800 1000
bb Invariant Mass (GeV, B)
0 200 400 600 800 1000
bb Invariant Mass (GeV, C)
0 200 400 600 800 1000
e+e− Invariant Mass (GeV, A)
0 100 200 300 400 500 600
e+e− Invariant Mass (GeV, B)
0 100 200 300 400 500 600
e+e− Invariant Mass (GeV, C)
0 100 200 300 400 500 600